

Invasions in aquatic systems: Patterns, mechanisms and management

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The 13th NEOBIOTA International Conference on Biological Invasions (NEOBIOTA 2024), held in Lisbon, Portugal, from 3–6 September 2024, brought together 421 participants from 47 countries for one of the most significant global gatherings in invasion science. Notably, this meeting featured the strongest representation of aquatic studies to date, spanning marine and freshwater systems across oral sessions, posters and workshops. This momentum contributed to the creation of a dedicated Special Issue, incorporating contributions from both conference participants and other aquatic researchers. This Special Issue on Invasions in Aquatic Systems comprises 23 papers — original research and reviews — organised into five themes: Responses to Environmental Stressors, Ecological Interactions and Invasion Impacts, Detection and Monitoring Tools, Management and Policy and Global and Regional Syntheses (Fig. 1). Collectively, these papers provide a data-rich snapshot of a rapidly evolving field and the challenges it faces.



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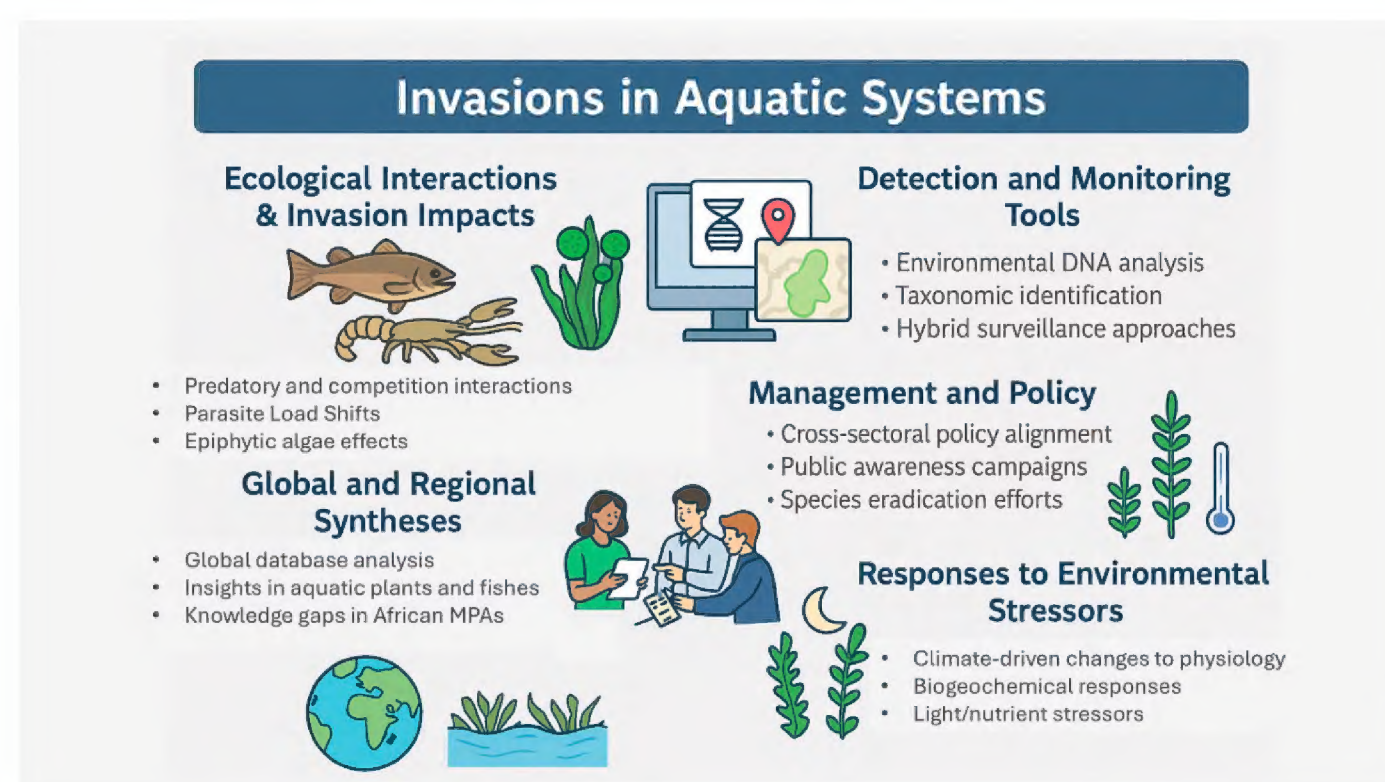


Figure 1. Overview of the five topics covered by the NeoBiota Special Issue on Invasions in Aquatic Systems.

Responses to environmental stressors

Biotic responses to abiotic drivers — such as warming, pollution or eutrophication — are central to predicting invasion success. Grewell et al. (2025) tested the salt tolerance of alligator weed (*Alternanthera philoxeroides*), showing that it functions as a facultative halophyte using stress tolerance, avoidance and escape strategies. Their findings on physiological plasticity suggest that increasing salinity intrusion in estuaries will not prevent and may even facilitate its spread. Another study connecting physiological plasticity with invasion trajectories, by Gonçalves et al. (2025) examined 57 chemical elements in the tissues of signal crayfish (*Pacifastacus leniusculus*) from populations at both core and invasion front. Invasion front individuals accumulated higher levels of cobalt, vanadium and mercury, likely linked to their behaviour and diet.

Physiological thresholds were explored by Rodríguez-Ruiz et al. (2025), who used Electron Transport System (ETS) activity to examine how temperature affects blue crab (*Callinectes sapidus*) embryos. Their identification of a reduced performance temperature (pejus) range of 24–26 °C suggests that, while warming may accelerate development, it also threatens larval viability of this invasive crab in the western Mediterranean Sea. Pereira et al. (2025) analysed how temperature and salinity affect survival and aggression in the blister anemone (*Phymactis papillosa*). While tolerant to salinity variations, this invasive species shows lethal responses to 31 °C, suggesting climate extremes may cap its invasive range despite its competitive dominance over native anemones, such as *Actinia* spp. Finally, Zhang et al. (2025) demonstrated that Artificial Light at Night (ALAN) and nutrient enrichment interact synergistically to enhance alien plant competitiveness in Chinese freshwater ecosystems. Their factorial experiment reinforces the need to address compound anthropogenic pressures.

Ecological interactions and invasion impacts

Interactions that invading species have with native species, as well as with other non-native species, are critical in determining the population dynamics and ultimately its ecological impacts. This group of papers includes studies dedicated to freshwater fish, crustaceans, amphibians, higher plants and algae, but also estuarine bivalves. For example, in an analysis of trophic interactions, Matos et al. (2025) assessed whether native brown trout (*Salmo trutta*) can serve as an effective biocontrol agent for the invasive signal crayfish. Although predation occurred, it was infrequent and size-dependent, casting doubt on the trout's viability as a standalone biological control strategy. In another study, Cabral et al. (2025) investigated feeding competition amongst three estuarine bivalves — including the non-native Manila clam (*Ruditapes philippinarum*) — and found overlapping capture efficiencies and clearance rates, suggesting a competitive impact on native species, such as the common cockle (*Cerastoderma edule*).

Fish-parasite dynamics were re-evaluated by Tkachenko et al. (2025), who documented a shift in parasite load amongst native perch and non-native pumpkin-seed sunfish (*Lepomis gibbosus*) in sympatric populations. Their findings highlight how invasions can alter host parasite community structure and facilitate the spill-over of parasites, affecting native host resilience.

At the interface of species interactions and invasion dynamics, Reshetnikov et al. (2025) explored predation between two widespread invaders — African clawed frog (*Xenopus laevis*) and eastern mosquitofish (*Gambusia holbrooki*). Through ontogenetic experiments, they revealed an asymmetric bidirectional predation regime, in which vulnerability changes with life stage and light availability. This work shows that there are no stable dominance relations in the interactions amongst these particular invasive species. Additionally, Shen et al. (2025) introduced a novel layer of biotic mediation by testing how epiphytic algae influence the suppressive effects of water hyacinth (*Pontederia crassipes*) and water lettuce (*Pistia stratiotes*) on submerged plant communities. Their mesocosm findings showed that algae can buffer invasion impacts, hinting at the potential of functional ecosystem components as tools in resistance-based management.

Detection and monitoring tools

Monitoring of non-native species has evolved beyond taxonomic surveys to incorporate the use of molecular tools, informatics and citizen science for detecting and monitoring non-native species. Dias et al. (2025) exemplified this shift by combining environmental DNA (eDNA) analysis with social media data-mining to track the spread of European perch (*Perca fluviatilis*) in Portugal. Their integration of real-time angler data and eDNA-based validation yielded new invasion records, demonstrating the power of hybrid surveillance models. Additionally, building on eDNA-based techniques, Everts et al. (2025) mapped the northernmost population of the African clawed frog using pooled eDNA samples, which enhance detection accuracy, while reducing cost in early-detection-rapid-response programmes.

In a taxonomic monitoring approach, Gkenas et al. (2025) employed morphological and molecular tools to identify hybrid *Squalius* fish populations, previously under-reported in Iberian freshwaters. Their findings, supported by citizen-science observations, stress the importance of integrative approaches (morphology and molecular tools) to prevent taxonomic errors due to hybridisation. Furthermore, in a marine case study from Chile, Rech et al. (2025) used a simple deployment of artificial settlement plates to reveal five previously undetected non-indigenous bryozoans. The clarity and affordability of the method make a strong case for routine monitoring in marine invasion hotspots.

Management and policy

Policy effectiveness and practical management are central concerns in invasion science (Roy et al. 2024). In this context, Magliozzi et al. (2025) analysed 602 invasive alien species (IAS) across nine EU policy sectors, uncovering a lack of cross-sectoral coordination that undermines integrated IAS management. Their workshop-based findings from NEOBIOTA 2024 highlight confusion over impact assessments and they urge greater policy harmonisation. Legislative limitations were also tackled by Rato et al. (2025), who assessed the European ban on the pond slider (*Trachemys scripta*). Although trade of this species has been halted, establishment continues and new invasive turtle species (e.g. *Graptemys* spp.) are appearing as substitutes. Their policy analysis calls for more tailored biogeographic risk lists and enforcement mechanisms.

In addition to comparing legislation targeting invasions, it is also valuable to evaluate specific management actions, including removal techniques. Carosi et al. (2025) offered a detailed report on crayfish eradication in Italy's Clitunno River. After nearly 260 removal events, a significant reduction in signal crayfish biomass was achieved, demonstrating the effectiveness of persistent effort in small-scale containment. In the Mediterranean Sea, Herrero-Reyes et al. (2025) conducted a two-year study on blue crab, assessing its population dynamics and habitat use in hypersaline lagoons. Their analysis of trap effectiveness revealed that fyke nets are the most efficient capture method, especially for subadult females, potentially aiding management in shallow estuarine environments.

Prevention is known to be one of the most efficient approaches for dealing with biological invasions, but prevention is tightly linked to public awareness. In this line, public awareness and institutional collaboration were emphasised in López-Cañizares et al. (2025), who documented the outreach and governance outcomes of the LIFE INVASAQUA project across the Iberian Peninsula. With 598 outreach events reaching over 246,000 people, their results show a remarkable scale of engagement and impact in raising literacy on aquatic invasive species.

Global and regional syntheses

Global and regional syntheses play a critical role in guiding invasion policy and future research and three regional and one global syntheses are provided in this issue. Ackland et al. (2025) focus on African Marine Protected Areas (MPAs), where they documented 27 alien species across 17 MPAs using open-access databases and iNaturalist observations. Their findings exposed major monitoring shortfalls, but also demonstrate the value of community science. Kumar et al. (2025) provide a much-needed systematic review of non-native freshwater fishes in India, detailing 58 invasive and 18 translocated species. They highlighted that, despite growing publication numbers, many studies lack quantitative impact data, emphasising the need for standardised assessments and open-access datasets. A European regional perspective was provided by Di Lernia et al. (2025), who critically reviewed 19 key invasive aquatic plants, identifying some well-studied species (e.g. water hyacinth), while noting that others remain under-researched. They observed that impact-focused publications are rare and called for more field-based studies and better integration with management practices. Finally, Kortz et al. (2025) delivered a comprehensive overview of naturalised aquatic plants, drawing on global databases to map introduction hotspots and identify knowledge gaps, especially in tropical zones.

Concluding remarks

This special issue offers a timely and multifaceted view of aquatic invasions, reflecting both disciplinary breadth and methodological sophistication. The assembled papers span a diversity of aquatic taxa, including fishes, crustaceans, amphibians, molluscs, macrophytes, bryozoans and even parasite-host systems. From functional trait ecology and trophic interactions to molecular diagnostics and policy assessments, the contributions demonstrate how aquatic invasion science is evolving towards greater interdisciplinarity and translational relevance.

Geographically, the issue features numerous case studies from Europe (16), but also from Asia, Africa, North and South America and a global review. However,

notable biogeographic gaps remain. Polar and subpolar ecosystems, deep-sea environments and freshwater systems in Central and Southeast Asia or the Pacific islands remain under-represented. These omissions highlight opportunities for future research and collaboration, particularly in regions with high biodiversity and growing anthropogenic pressures.

Together, these articles underline the dynamic and often context-dependent nature of biological invasions in aquatic systems. They also emphasise the need for cross-sectoral integration, early detection innovations and adaptive management strategies to confront the expanding frontiers of invasion risks. We hope this Special Issue not only advances scholarly dialogue, but also provides information for concrete solutions for aquatic invasions, while preserving aquatic biodiversity and ecosystem function globally.

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Additional information

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The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

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Data availability

All of the data that support the findings of this study are available in the main text.

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